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Specially conditioned EM fields to reduce nuclear fusion input energy needs

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Abstract

Ordinary electromagnetic (EM) fields possess relatively simple U1gauge symmetry, and their angular momentum is analogous to that of spin1 particles whose likecharges attract and unlike charges repel. This manifests in coulomb repulsion between free electrons or ions and coulomb attraction between free electrons and ions. By contrast, angular momentum of SU(2) fields that describe the shortrange Weak Nuclear Force in atomic nuclei is analogous to that of spin2 particles whose likecharges attract. So, free ions that enter such small SU(2) field regions attract each other until their separation becomes so small that their fusion occurs. In this respect, Barrett has derived EM fields with the same SU(2) gauge symmetry and spin2 angular momentum as SU(2) matter fields in atomic nuclei. It is conceivable, therefore, that SU(2) EM fields might cause fuel ions inside nuclear fusion reactors to attract (rather than repel) each other. This paper, therefore, explores the possibility of SU(2) EM fields reducing the electrical compression energies these SU(2) EM fields must exert on fuel ions before fusion of the ions by the SU(2) matter fields of the weak nuclear force then occurs. A specific conditioning of U(1) EM field energy into SU(2) EM field energy was selected; a given type of fusion was assumed; and preliminary, parametric estimates of input electrical energy reductions were made.

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1. Specially conditioned electromagnetism

Ordinary electromagnetic (EM) fields possesses U(1) Lie group symmetry and angular momentum that is analogous to the angular momentum of spin1 particles like free ions, whose likecharges repel. By contrast, the matter fields associated with the weak nuclear force in atomic nuclei possess higher SU(2) symmetry; and their angular momentum is analogous to that of spin2 particles (like any ions confined in these fields – ions which attract each other until their fusions occur). In this respect, SU(2) EM fields with angular momentum analogous to spin1 particles have been derived by one of us (Barrett). It is, therefore, conceivable that SU(2) EM fields in reactors (like SU(2) matter fields in nuclei) could cause ions inside them to attract each other. If so, fuelcompressing, ionattracting SU(2) EM fields inside nuclear reactors would face less repulsive resistance and, thus, need to expend less EM field energy to accomplish fusion.
In most cases, EM radiation fields are correctly and adequately described by the classical Maxwell equations which is a theory of U(1) symmetry form. However, in special situations, specially conditioned EM radiation fields can be produced that require an extension of Maxwell theory to higher symmetry. For such situations, Barrett [1] has used topology, group and gauge theory to derive specially conditioned SU(2) EM radiation fields. Even more complex EM fields are describable by more complex symmetry groups like SU(3) and even higher SU(5) groups. However, this paper only addresses SU(2) EM fields.

1.1 Maxwell equations for conventional and specially conditioned EM fields

Using group theoretic methods, EM radiation fields of SU(2) symmetry can be created by special conditioning of conventional U(1) EM fields. U(1) EM fields are described by Maxwell's equations in Table 1. They describe electric field strength (**E**), magnetic flux density (**B**) and current density (**J**). The **E** and **B** fields of force can be related to a vector potential" (**A**) and a "scalar electric potential" (φ) that, themselves, are not physical. However, they are of mathematical convenience in U(1) EM field theory.

Table 1. The four Maxwell vector field equations for conventional U(1) symmetry electromagnetic radiation fields

Gauss' Law	$\nabla \bullet \boldsymbol{E} = \boldsymbol{J}_0$
Ampere's Law	$\frac{\partial \boldsymbol{E}}{\partial t} - \nabla \times \boldsymbol{B} - \boldsymbol{J} = 0$
Coulomb's Law	$\nabla \bullet \boldsymbol{B} = 0$
Faraday's Law	$\nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} = 0$

$$E = -\frac{\partial A}{\partial t} - \nabla \phi, \quad B = \nabla \times A$$

In the SU(2) field theory, Barrett [1] shows that the potentials **A** and φ have actual physicality. Table 2 shows extended Maxwell equations that describe propagation of specially conditioned SU(2) EM fields. These Maxwell equations are described by tensor, rather than vector quantities. SU(2) Maxwell equations include **E** and **B** fields just as U(1) Maxwell equations do. But they also include added tensor field terms that include imaginary number i (viewed as either square root of 1 or as an orthogonal rotation occurring in x, y, z, ct spacetime) and electron charge (q). These added tensor field terms describe added **AxE** and **AxB** and **A•E** and **A•B** interactions (Barrett [1] on p 145147). All tensors (matrices) function as operators that obey noncommutative, nonAbelian algebra. So, unlike vector multiplication, the product (**A•B)** doesn't equal (**B•A)** and (**AxB**) doesn't equal (**BxA**) in the matrix algebra of SU(2) fields.

Table 2. The four Maxwell tensor EM field equations for conditioned SU(2) symmetry electromagnetic radiation

$\nabla \bullet \boldsymbol{E} = \boldsymbol{J}_0 - iq(\boldsymbol{A} \bullet \boldsymbol{E} - \boldsymbol{E} \bullet \boldsymbol{A})$
$\frac{\partial \boldsymbol{E}}{\partial t} - \nabla \times \boldsymbol{B} - \boldsymbol{J} + iq[\boldsymbol{A}_0, \boldsymbol{E}] - iq(\boldsymbol{A} \times \boldsymbol{B} - \boldsymbol{B} \times \boldsymbol{A}) = 0$
$\nabla \bullet \boldsymbol{B} + iq(\boldsymbol{A} \bullet \boldsymbol{B} - \boldsymbol{B} \bullet \boldsymbol{A}) = 0$
$\nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} + iq[\boldsymbol{A}_0, \boldsymbol{B}] = iq(\boldsymbol{A} \times \boldsymbol{E} - \boldsymbol{E} \times \boldsymbol{A}) = 0$

The Lorentz force (**F**) plays important roles in the plasma dynamics of many nuclear fusion processes. It arises from an electromagnetic interaction that involves **E** and **B** fields and the velocity (**υ**) of moving particles with a charge (e). Table 3 shows Lorentz force equations for U(1) EM vector fields in terms of magnetic vector potentials and electric scalar potentials. It also shows Lorentz force equations for SU(2) tensor fields, in terms of these vector and scalar potentials. SU(2) Lorentz forces contain extra terms that include these potentials. So, they can be of different magnitude and direction than U(1) Lorentz forces.

Table 3. Comparison of Lorentz force equations for U(1) symmetry and SU(2) symmetry EM fields from Barrett [1].

U(1) Lorentz Force	$\mathscr{F} = e\mathbf{E} + ev \times \mathbf{B} = e\left(-\frac{\partial \mathbf{A}}{\partial t} - \nabla\phi\right) + ev \times \left((\nabla \times \mathbf{A})\right)$
SU(2) Lorentz Force	$\mathscr{F} = e\mathbf{E} + ev \times \mathbf{B} = e\left(-(\nabla \times \mathbf{A}) - \frac{\partial \mathbf{A}}{\partial t} - \nabla\phi\right) + ev \times \left((\nabla \times \mathbf{A}) - \frac{\partial \mathbf{A}}{\partial t} - \nabla\phi\right)$

1.2 Example of the special conditioning of an ordinary U(1) EM field into an SU(2)symmetry EM field

An example of ordinary U(1) EM field energy being transformed into specially conditioned SU(2) EM field energy is described on pages 46 and 61 of Barrett [2]. This example uses a wave guide system paradigm to portray oscillating U(1) EM wave energy being transformed into SU(2) EM wave energy by phase and polarization modulation. Figure 1 shows a completely adiabatic system where oscillating wave energy: enters from the left; divides into 3 parts; is modulated and recombined; and exits from the right. One part of the input wave energy is unchanged, another part of the input wave energy provides phase modulation ($\partial\varphi/\partial t$) and then combines with an orthogonally polarized part that has passed through a "polarization rotator". Two orthogonally polarized oscillating wave forms (with one being the unchanged fraction of oscillation wave energy) result. The two wave forms are then superimposed at an output where they are combined into a single EM beam of emitted SU(2) radiation. Owing to phase modulation of one waveform with respect to the other, and their initial orthogonal polarization, the output SU(2) radiation is of continuously varying polarization during one cycle of wave oscillation. This is symbolized by the diagram in the lower right hand portion of Figure 1. This diagram represents timevarying E and Bfield

polarizations that traverse continuously through: horizontallinear; rightverticalelliptical; rightcircular; righthorizontalelliptical; horizontallinear; lefthorizontalelliptical; leftcircular; leftverticalelliptical polarization during a polarization modulation period Δt. And, here: $\partial\varphi/\partial t$ = constant and $0 < \varphi < 360^{\circ}$.

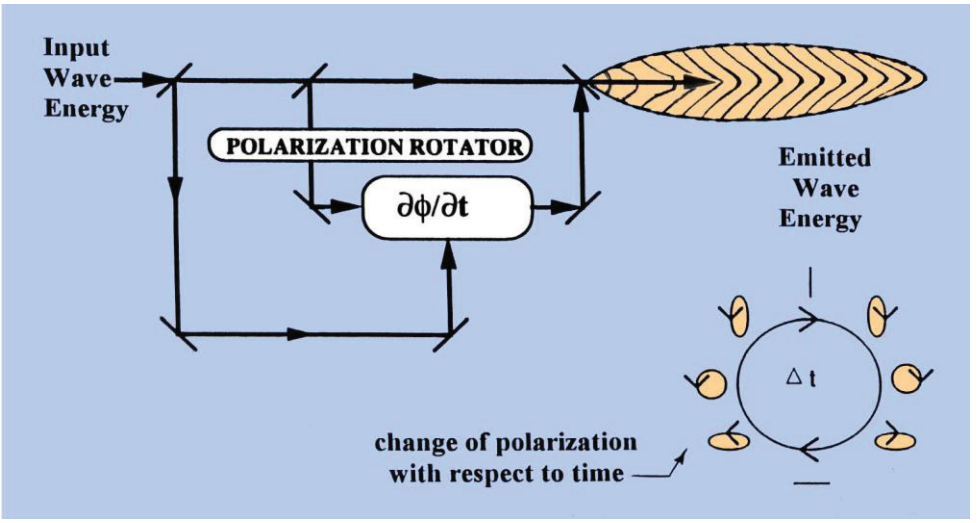

Figure 2, from Barrett [1] shows the magnitude and direction of the electric field E within a beam of SU(2) EM radiation during a cycle of its phase and polarization modulation. It is seen that magnitude and direction of the electric field can vary rapidly during one cycle of phase and polarization modulation and that many E field rotations can occur during a very short time and over a very short length of beam travel.

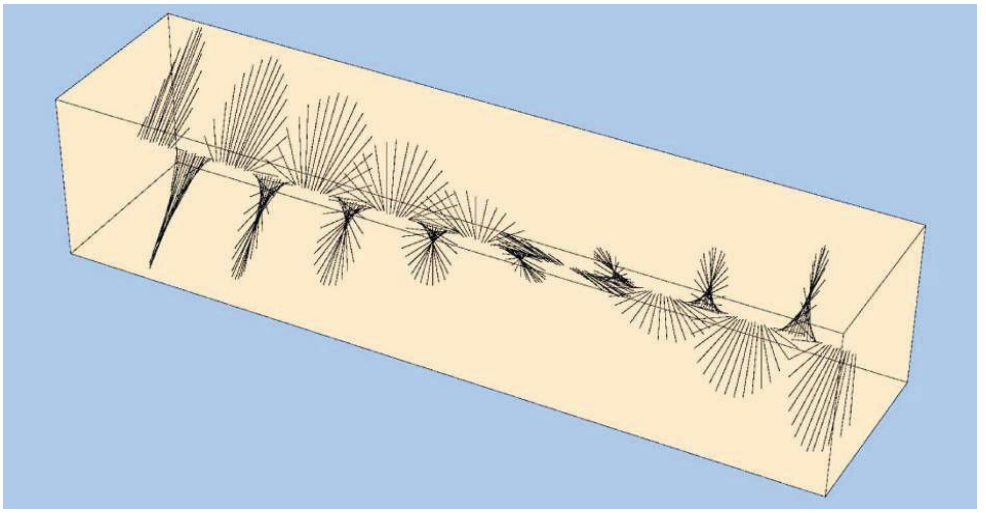

Figure 2. Rapid change in electric field vector direction and magnitude over a very short time and very short distance

Rapid electric and magnetic field rotations in SU(2) EM beams, combined with rapid change in field intensity result in different angular dynamics than that of U(1) EM beams with fixed linear or circular or elliptical polarization. And different angular dynamics of U(1) and SU(2) EM beams could possibly be reflected in repulsion of spin1 ions in U(1) EM beams and attraction of spin2 ions in SU(2) EM beams.

2.0 Polarizationmodulated SU(2) EM fields for Inertial Electrostatic Confinement fusion systems

We explored the possibility of SU(2) EM fields lowering electrical input energy needs for fusion in certain "Inertial Electrostatic Confinement" (IEC) nuclear fusion systems. One IEC nuclear fusion system uses a central, negatively charged electrode (a grid) that draws many converging streams of positively charged ions from plasma injectors (RF ion guns) located around the reaction chamber periphery. Figure 3 shows such an IEC system at the University of Illinois accomplishing hundreds of fusions per second.

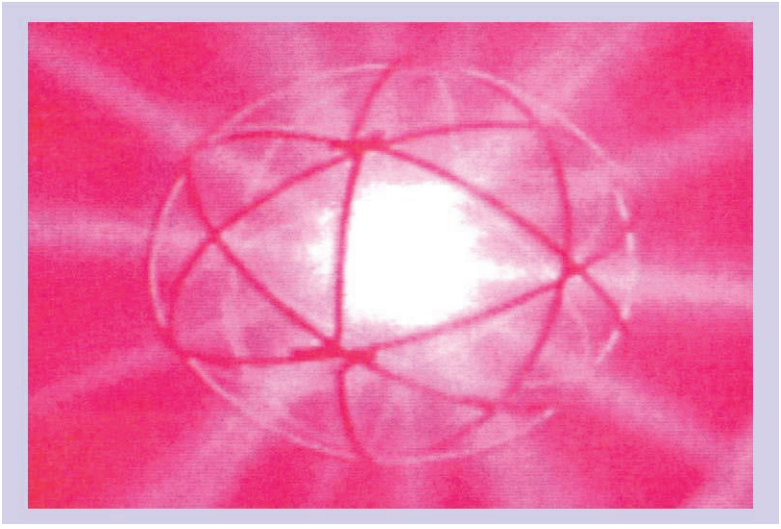

Figure 3. Operating IEC Fusion Reactor accomplishing hundreds of DD fusions per second at University of Illinois

Each radial ion stream in Figure 3 is emitted from a plasma generator that contains: nuclear fusion fuels; needed electrical power; and radiofrequency (RF) antenna discharges to transform fusion fuels into plasma and transform plasma into a focused ion beam. Figure 4 shows an IEC system installation at the University of Illinois with one of many plasma generators (one of many RF ion guns) that are needed.

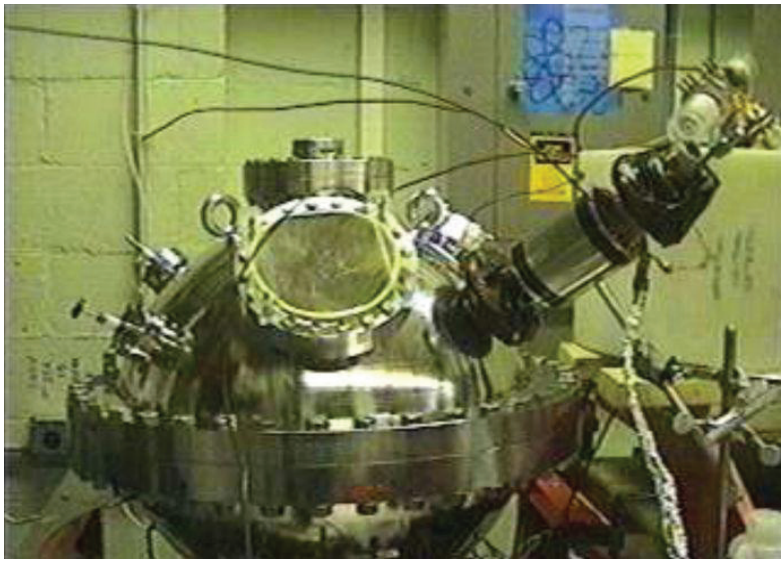

Figure 4. IEC fusion reactor chamber with helicon plasma injector (RF ion gun) operated at the University of Illinois

Each circumferentiallydistributed injector contains a radio frequency (RF) antenna system that deposits pulsed energy into nuclear fuel material in the injector, transforming the material into flowing plasma. A magnetic field is also induced by current flow in windings. Such a plasma injector, developed by Miley at the University of Illinois [3], is shown in Figure 5. High power (13.5 MHz) discharges are caused by RF wave propagation through a coaxial copper helical resonator consisting of a singlelayer coil inside a copper shield**.** The RF system's helical coil antenna is magnet wire that is wound directly to a glass tube.

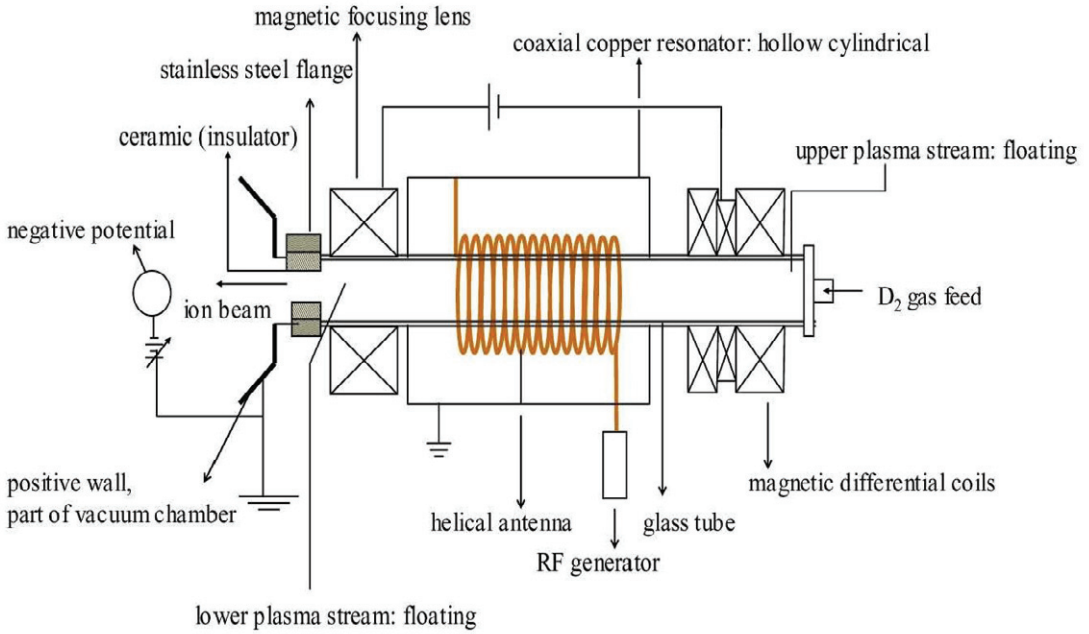

Figure 5. Typical schematic of one of the plasma injectors that are circumferentiallydistributed about an IEC reactor

Barrett's transforming of ordinary U(1) EM waves into SU(2) EM waves is extended to EM plasma waves emitted from plasma injectors. Windings and antenna elements of each injector would be modified to modulate both phase and polarization of the created SU(2) EM beam and favorably effect electrons and ions inside it. If SU(2) field content causes some ion attractions, coulomb resistance to applied EM input power will lessen, So, less input energy need be expended by ionattracting SU(2) EM fields in bringing ions close enough for SU(2) weak force matter fields in the ion nuclei, themselves, to cause their fusion.
We are now exploring possibilities for adding another set of helicon windings to the existing set. Such a circuit would "wiggle" RF discharges somewhat like an undulator (wiggler) in a free electron laser (FEL) accelerates and decelerates electrons. Electron accelerations and decelerations in a FEL can give off enormously complex and varied bursts of EM radiation as FEL undulator is 'played' like a very highly tuned musical instrument. Therefore, a critical issue is helicon windings (or selective driving of helicon windings) to provide control precision that may have to approach that of very large and complex FELs.
One concern is interaction of SU(2) ion beams from modified plasma generators with the U(1) electric field of the negativelycharged grid. Such interactions are not yet understood. Thus, it is possible that the grid's negativelycharged U(1) electric field could: (a) repel rather than attract ions in the SU(2) beam; or (b) quench the SU(2) field itself. One alternative might be to reverse the polarity of the grid. Another might be to remove the grid entirely and to let the mutual attraction of the merging nuclear fuel ions from the many converging SU(2) ion beams coalesce themselves naturally into a central region of increasing ion compactification. Hopefully, this would create a deep potential well of increasing ion attraction a deep well that would enable final fuel ion fusion by the SU(2) matter fields in the fuel ions, themselves.

3. Recommended early experiments involving SU(2) EM Field generation in a helicon plasma gun

Theoretical explorations of possibilities for ionattracting SU(2) EM plasmas will, of course, require much work. And early experiments, to augment and guide early analysis, are needed. Early experiments would involve modification of a helicon plasma generator for SU(2) ion beam emission. This need not involve expensive nuclear fuel plasmas. Instead, more ordinary, inexpensive plasmas from RF discharges in gases such as Argon or Xenon can be created in a wellinstrumented helicon plasma generator. Figure 6 shows an instrumented helicon plasma generator that is located at the Australian National University.

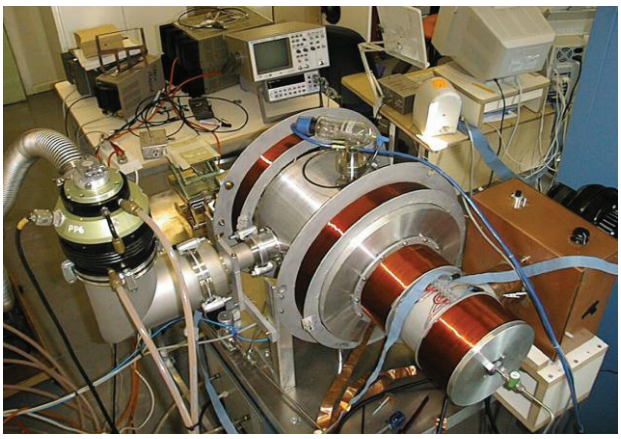

Figure 6. Helicon plasma generator in the Plasma Dynamics Laboratory of the Australian National University

Figure 7, illustrates some of the plasma properties that can be measured inside the Australian National University's helicon plasma generator shown in Figure 6. Typical measurements, described in [4] include plasma voltage and current mapping throughout the plasma generator chamber; ion speeds; voltage and energy variation (with high spatial and temporal resolution) within the beam. Such kinds of measurements and resolutions are needed to detect ionion attractions and ionelectron repulsions in SU(2) plasmas.

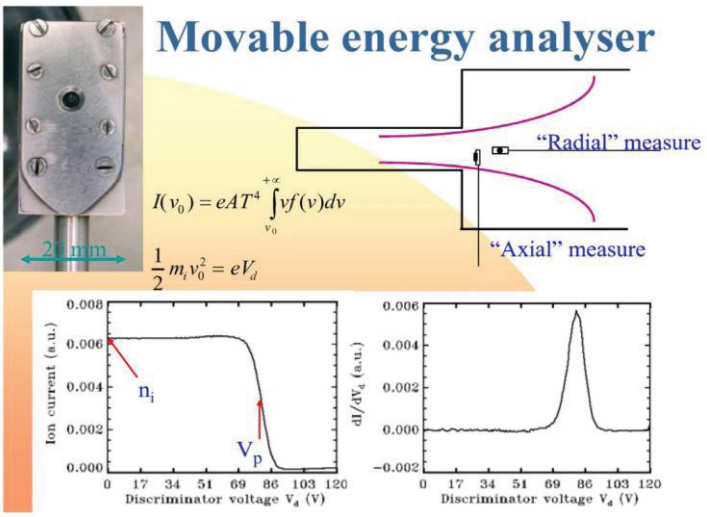

Figure 7. Energy analyzer that maps plasma properties and flows throughout the interior of the plasma generator

4. Preliminary analyses of potential reductions in fusion input energy needs with SU(2) EM fields

Figure 8, from Duncan [5], shows the effect of input electrical power (in thousands of electron volts) on the crosssectional areas of regions where ion fusions can occur. These areas are usually described in units called "barns", where a barn is 1.5 x 10^{28} m^2, the approximate area of a uranium nucleus. It follows that fusion crosssection sizes are associated with numbers of ion fusions and amounts of fusion power.

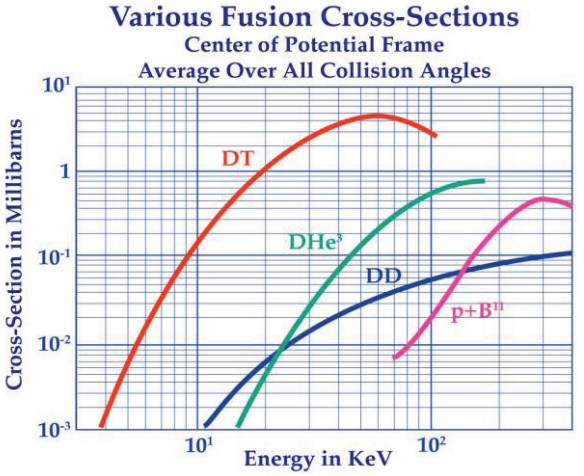

Figure 8. Crosssections of reaction regions where nuclear fusions occur as a function of input electrical field energy

Since we cannot yet claim that SU(2) EM fields can induce attractions between ions, it is certainly not possible to predict any input energy reductions these fields can provide. Possible input energy reductions, if any, would have to be ascertained by experiments with existing IEC reactors and ion guns. However, preliminary parametric explorations are possible with fusion cross section and input energy information from sources like Figure 8 and by assuming certain SU(2) ion attracting and electron repelling scenarios.

SU(2) EM field creation and its accomplishment of ion attracting states can be viewed as the product ($\alpha\beta$) of two efficiencies – with α: the efficiency in creating SU(2) EM field energy by phase and polarization modulation of input U(1) EM field energy in IEC ion guns; and β: the efficiency of created SU(2) EM field energy in mulling fuel ion repulsions in IEC fusion reactors. It follows that: (1α) is the fraction of input energy dissipated during the phase and polarization modulation processes that create SU(2) field energy; while (1β) is wasted field action from EM couplings that hamper achievement of ion attractions in SU(2) EM beams. Such couplings can begin as soon as RF discharges create electronion clouds and screening from intervening electrons hamper initial attractions of ions inside these clouds.

Increased input field energy force ions into closer proximity to increase probability and numbers of their fusions. And increased cross sectional areas reflect increased numbers of ion fusions. For example, Figure 8 shows a modest 4 KeV of EM input energy enabling only a modest amount of DT fusion inside a small (10^3 millibarn) cross section. But, a 24fold increase in input energy to 200 KeV results in 10^3 fold increase in fusion crosssection to 1 millibarn and a 10^3 fold increase in fusion output energy. Thus, if ionattracting SU(2) EM fields could null all fuel ion repulsions within a 1.0 millibarn crosssectional area area by the time 4 KeV of EM field energy is spent, no more energy expenditure would be needed, For all ions in this region would now be attracting and moving ever closer until their fusion by the SU(2) fields of the weak nuclear force occurs at distances of about a 10^3 millibarn area. Hence, 4 KeV of input

SU(2) EM field energy – if generated with negligible losses by polarization modulation of U(1) EM field energy would achieve the same output fusion power as 200 KeV of ordinary U(1) EM energy provides.

Figure 9 illustrates this. It indicates that if SU(2) EM fields could cause ion attractions over distances 10^{34} to 10^{15} times longer than the 10cm range of the ionattracting, fusioncausing weak nuclear force, input energies could be reduced by factors of 10 to 20 for achieving a given DT fusion power. In this scenario, ionattracting SU(2) fields cause fuel ions to be drawn closed and closer by mutual attraction until their fusions are accomplished by the SU(2) matter fields associated with the weak nuclear forces in the ions themselves. Significant reductions in input energy are seen to be achievable, even for fairly poor field efficiencies (αβ of 1.0 % to 10 %.), if ionattractions in SU(2) EM fields can occur over distances that are 10^{24} to 10^{15} times the 10cm distance where fuel ion fusion can occur. It must also be mentioned that Figure 9 assumes all fuel ions transition from repelling to attracting at the same time. But, of course, ions actually reach attracting state at different times, so ion resistance to compression is reducing long before all ions become attracting. Figure 9 calculated input energy is, thus, more than is actually needed.

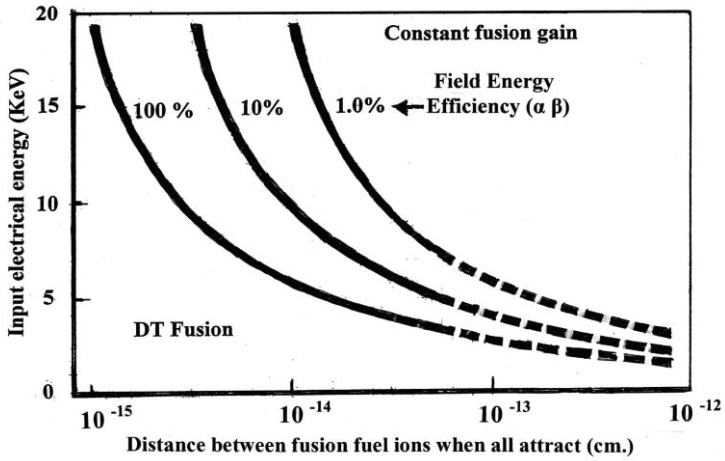

Figure 9. Influence of distance between fusion fuel ions when all become attracting on reduction in input energy to achieve a given DT fusion output power. Dashes denote extrapolation of Figure 8 reaction crosssection information.

A very clean nuclear fusion reaction is fusion of Hydrogen and Boron 11 nuclei. Figure 10, from [5], shows this reaction culminating in: the energy of 3 charged helium ions (which can be converted directly to electricity); no harmful, radioactivitycausing neutron emissions; and, hence, little radiation shielding.

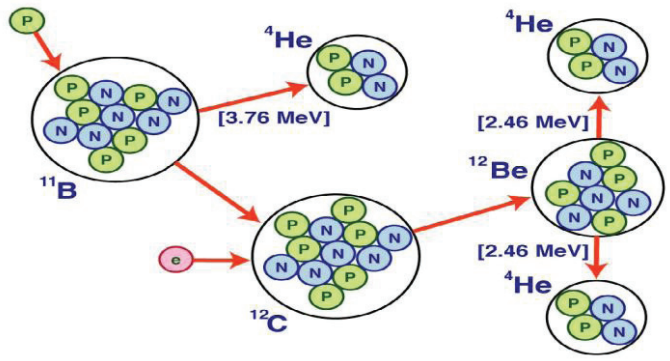

Figure 10. Aneutronic pB11fusion resulting in 8.68 MeV of energy and the electricity of 3 Helum 4 Ions

Effective, ionattracting SU(2) EM field interactions would generate fusion power with less electrical input energy for any of the fusion reaction in Figure 8. However, "clean" pB11 reactions, which result in very low radioactivity because very few neutrons are emitted, might benefit most from SU(2) EM fields.

Figure 8 shows pB11 fusion reactions requiring about 15times more input energy than lessclean DT fusion reactions to achieve a given fusion power. This results in higher ignition temperatures which can cause phenomenon such as bremsstrahlung radiation losses that certain fusion systems find very difficult to prevent or to cope with. Figure 11 compares reduced input energy needs for DT and pB11 fusion for a given fusion output power and for a fairly modest SU(2) EM field efficiency (αβ) of only 10 percent.

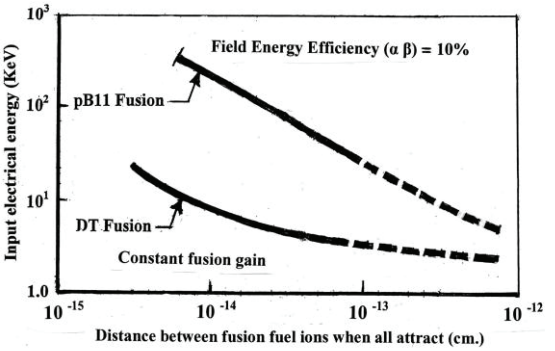

Figure 11. Obtaining longer ion-attracting range in SU(2) EM fields reduces DT and p-B11 fusion input energy needs

Aneutronic pB11 fusion is seen to requires more input energy than DT fusion for a given reaction distance. But, ionattracting SU(2) EM fields are seen to enable larger input energy reductions for pB11 fusion than for DT fusion. If so, these reductions should avoid things such as bremsstrahlung radiation.

Conclusions

Barrett has shown the possibility of EM radiation fields with the same SU2 gauge symmetry as the ion-attracting matter fields associated with ionattracting, weak nuclear forces in nuclei that cause fusion. If so, ionattracting SU(2) EM radiation fields in fusion reactors could conceivably attract (rather than repel) fusion fuel ions to reduce the coulomb resistance and electrical compression energy needed for fusion of these ions. So, the authors have begun exploring this seemingly bizarre possibility theoretically. However, an experiment to modify a helicon plasma generator to create SU(2) EM discharges and ion beams, and to search for ionion attractions and ionelectron repulsions inside the generator is also a needed first step.

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